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Joint Electrification of Steam & Electric Railways

Electrical Engineering

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JOINT ELECTRIFICATION OF STEAM AND ELECTRIC RAILWAYS

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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JOINT ELECTRIFICATION OF STEAM AND ELECTRIC RAILWAYS.

I. Introduction.

1. Preliminary.- The purpose of this investigation is to determine the feasibility of the joint electrification of all steam and electric railways of the United States. There are a great many indications that point in this direction and the question has been frequently touched upon by engineers of high standing, who are in a position to realize the trend of engineering development. It is the intention, however, to merely assemble the available data on this subject and to present unbiased results, and it is the desire to take the same attitude in the matter as that taken by Samuel Insull who, in a paper before the American Institute of Electrical Engineers in June 1912, said - "It is reasonable that I should assume that the electrification of steam railroads has come to stay, that the work done by the premier trunk lines centering in New York is a sufficient indication of what we may expect in the future. I am not in sympathy with an agitation to force the steam railroads in this country to electrify. That is a question of the provision of the capital necessary for the purpose, and that question must be taken up and settled by those who are responsible for the operation of the properties." It is along the lines of the last remark quoted that this paper deals, namely, to determine in a

preliminary manner whether there would be sufficient returns on the capital necessary to jointly electrify all railroads at the present time.

2. Advantages of Electrification.--Among the advantages for electrification of steam railroads, as outlined by Edward P. Burch in his book entitled - "Electric Traction for Railway Trains" are the following:-

1. Economy of operation on trunk lines. Saving in power, wages and maintenance.

2. Cheaper power from fuels and cheaper power from water power.

3. Capacity, draw-bar pull and speed for rapid transit and dense passenger service.

4. Economy and capacity on mountain grade railroads and in heavy freight haulage.

5. Smoke nuisance, exhaust noise and fire risk avoided.

6. Compulsory for safety and comfort at railroad terminals and yards.

7. Financial situation relieved; lost traffic regained; new business induced.

8. Demand for frequent and rapid suburban service and the necessity for increasing the carrying capacity and the speed of trains without excessive capital expenditure.

There is greater flexibility in the operation of electric railroads. Two electric locomotive units can be controlled from the cab by one operator, whereas with steam locomotives two engineers and two firemen are needed.

There is greater simplicity of moving parts in the electric locomotive as compared to the steam locomotive.

Greater reliability results from the simplicity of operation of electric trains.

There is better safety to life and property for the following reasons as stated by the same writer:-

1. The design of electric motors avoids tr ck pounding.
2. Control circuits prevent accidents.
3. Automatic devices safeguard operation.
4. Speed may be decreased with safety, or limited by design.
5. Long wheel bases are avoided on trucks.
6. Vigorous tests are easily made.
7. Regeneration of energy in braking prevents accidents.
8. Tunnels are made safer.
9. Boilers are avoided.
10. Fire risk to property is decreased.
11. Exhaust steam and smoke are absent.
12. Engine men are not distracted from their duty.
13. Electric meters assist in operation.
14. Weights are not excessive so as to spread rails.

The financial advantages are:-

1. Gross earnings are increased.
2. Operating expenses are decreased.

3. Disadvantages to Electrification.-- The principal disadvantage to electrification is the danger to employes and the public from the use of electric power.

Another disadvantage which might be stated is the necessity in electrification of depending upon electric power plants for the entire motive power. This, however, can be obviated by the joint electrification of all railways and properly linking the generating

stations, and by duplication of transmission lines.

4. Advantages of Joint Electrification.--Among the advantages favoring joint electrification and operation of all railways are the following:-

1. Avoidance of duplication of lines between given centers.

2. Ability to obtain tne maximum service from any one connecting line.

3. Better safety to passenger traffic which could be obtained by concentrating efforts on the lines used.

4. The concentration of power and power sources.

The factors which favor a comprehensive transmission and distribution system for serving any large territory rather than disconnected central stations as summarized by Wm. B. Jackson in a paper before the American Institute of Electrical Engineers in February 1911, were stated as follows:-

1. Saving in powerhouse equipment made possible through taking advantage of the diversity factor of the different communities by serving them from the same transmission system.

2. Lower power generating costs per kilowatt-hour due to larger power plants and improved load factor.

3. Less investment in power plants per kilowatt capacity on account of larger plants as compared with smaller.

4. The possibility of decreased percentage of spare apparatus by appropriate arrangement of power plants.

5. Saving in costs made possible by centralized management, general superintendence and other general expenses.

6. The possibility of providing rural and suburban service that could not be profitably reached by local central stations.

7. The possibility of large corporations providing power service which would be to extensive for small companies to undertake.

8. The development of water power for electric service.

II. ELECTRIC POWER REQUIRED TO OPERATE RAILWAYS.

5. Present Electric Railways, Jointly Electrified.--In determining upon the power required to operate the present electric railways of the United States, the best available information at hand is that contained in the McGraw Electric Railway Manual for 1911 which gives the statistics for electric railways for the fiscal year 1910.

In Table I, Columns a, b, c, d, e, f and g, are given the statistics compiled from this manual by groups of states. The grouping adopted is that used by the Interstate Commerce Commission in its reports entitled - "Statistics of Railways in the United States" - which is approximately as follows:-

Group 1. Main, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island.

Group 2. New York, Pennsylvania, New Jersey, Delaware, Maryland.

Group 3. Ohio, Indiana, Michigan.

Group 4. West Virginia, Virginia, North Carolina, South Carolina.

Group 5. Kentucky, Tennessee, Mississippi, Alabama , Georgia, Florida.

Group 6. Illinois, Wisconsin, Iowa, Minnesota, North Dakota.

Group 7. Montana, Wyoming, South Dakota, Nebraska.

Group 8. Missouri, Arkansas, Kansas, Oklahoma, Colorado.

Group 9. Texas, Louisiana, New Mexico.

Group 10. Washington, Oregon, Idaho, California, Nevada, Utah, Arizona.

Column h. Table I, gives the calculated operating expenses of all the electric railways in each group, assuming that the operating expenses of all the companies are proportional to the operating expenses of the reporting companies as

TABLE 1.

Power Required By Electric Railways in the United States, Jointly Electrified.

a	b	c	d	e	f	g	h	i	j	k
				Reporting Companies						
Group	No. of Ry. Co's.	Miles of Track	No. of Cars	No Ry. Co's	Miles of Track	Operating Expenses	Calculated Total Operating Expenses for all Companies	Calculated Total Car Miles	Kilowatt-Hours Required Per Year	Maximum Demand at Contacts 40% Load Factor.
							$\frac{c}{f} \times g$	$h \div 0.152$	$i \times 2.6$	$\frac{j}{8760} \div .40$
		Miles			Miles	Dollars	Dollars	Car Mile	Kw. Hour	Kw.
I	132	5 430	15 327	101	5 136	28 635 335	30 300 000	199 000 000	518 000 000	146 000
II	462	11 327	32 770	245	10 647	102 495 015	109 000 000	717 500 000	1 865 000 000	527 000
III	160	7 827	10 684	90	6 905	32 152 153	36 400 000	239 000 000	622 000 000	176 000
IV	58	1 061	1 826	18	553	3 863 738	7 420 000	43 800 000	113 800 000	32 300
V	69	1 818	3 668	29	1 497	11 637 571	14 140 000	93 000 000	243 800 000	68 300
VI	153	5 157	11 011	72	4 637	46 883 682	52 100 000	342 500 000	890 000 000	251 000
VII	17	392	737	5	268	2 360 000	3 450 000	22 860 000	59 400 000	16 800
VIII	81	2 146	4 170	24	1 540	15 840 953	22 100 000	145 200 000	377 000 000	106 500
IX	46	892	1 781	12	596	7 805 003	11 670 000	76 800 000	199 700 000	56 400
X	101	4 038	7 627	24	2 217	20 402 792	37 200 000	245 000 000	637 000 000	179 700
Total U.S.	1 279	40 088	89 601	620	33 996	272 076 243	323 780 000	2 124 660 000	5 525 700 000	1 560 000

the miles of track operated; values in Column h being equal to values in Column g times values in Column c divided by values in column f.

Column i gives the calculated car miles, being based on the assumption that the average operating expenses per car-mile is 15.2 cents, as indicated by a table given by Burch in his treatise before mentioned, on Page 48. This figure is also substantiated by innumerable other sources, but may be slightly low, making the number of car-miles slightly large.

Column j gives the kilowatt hours required per year based on 2.6 kilowatt-hours per car-mile, which figure was derived as follows:-

Average weight of car ....30 tons

Average power consumption per ton............70 watt-hours
25% additional power required in Winter
on account of cold and for heating cars....17.5 watt-hours

Total average power consumption per ton-mile 87.5 watt-hours
Total average power consumption per
car-mile, 30 x 87.5 ....2.6 kilowatt-hours

Column k gives the maximum demand at contacts, based on 40% load factor.

6. Present Steam Railroads, Jointly Electrified.-- On account of the nature of available information on steam railways, it was considered sufficient to assume that all tracks and lines would be electrified. There are, of course, some cases such as some logging roads where the traffic is not sufficient to warrant more than a single gasoline car, but the percentage of such roads, or other questionable roads, is so small that the ultimate conclusions of the investigation would not be seriously effected.

Taking the statistics contained in the previously mentioned Interstate Commerce Commission Report for the year 1910, Table II was compiled.

Columns a, b, c and d give the locomotive-miles and car-miles for the different types of cars and kinds of service.

TABLE II.

Power Required by Steam Railroads in the United States, Jointly Electrified.

a	b	c	d	e	f	g	h	i	j
Kind of Service	Locomotive-Miles Millions	Kind of Cars	Car-Miles Millions	Est. Av. Tons Per Car	Ton-Miles = b x e or d x e Millions	Watt-Hours Per Ton Mile	Kilowatt-Hrs. Per Year $\frac{g \times f \times 1.25}{1000}$ Millions	Load Factor	Maximum Demand $\frac{h \times 1,000,000}{8760 \times i}$ Kilowatts
Freight	722.8	--------	-----	90	65 000.	70	5 680.	.70	927 000
Freight	---	Empty Cars	5 498.3	20	110 000.	30	4 125.	.70	673 000
Freight	---	Loaded Cars	12 851.3	50	642 000.	30	24 080.	.70	3 930 000
Freight	---	Caboose	631.3	10	6 300.	30	236.	.70	38 500
Passenger	567.0	--------	-----	90	51 000.	70	4 400.	.40	1 258 000
Passenger	---	Coaches	1 420.4	35	49 700.	40	2 484.	.40	708 500
Passenger	---	Pullman	628.2	70	44 000.	40	2 200.	.40	628 000
Passenger	---	Other	949.6	50	47 500.	40	2 380.	.40	680 000
Mixed	37.0	Trains	-----	500	18 500.	40	925.	.40	264 500
Special	1.8	Trains	-----	90	162.	70	14.	.40	4 060
Special	---	Loaded Fr't.	6.1	50	305.	30	11.4	.40	3 260
Special	---	Empty Fr't.	.1	20	2.	30	0.1	.40	29
Special	---	Caboose	.4	10	4.	30	.2	.40	57
Special	---	Pass.Coaches	3.4	35	119.	40	5.9	.40	1 687
Special	---	Pullman	1.2	75	90.	40	4.5	.40	1 288
Special	---	Other Pass.	1.3	50	65.	40	3.2	.40	914
Switch	316.6	--------	-----	250	79 100.	120	11 870.	.75	1 807 000
Non-Rev.Ser.	69.2	Trains	-----	400	27 700.	32	1 108.	.40	316 000
T o t a l-	1 714.4	--------	21 991.6	---	1 125 647.	53	59 527.5	.62	10 925 795

Column e gives the assumed average weight per car as obtained from the same and other sources.

Column f gives the ton-miles, being the product of Column e and Column b in the case of locomotive ton-miles, and the product of Column e and Column d in the case of car ton miles.

Column g gives the assumed watt hours per ton mile for the different kinds of service, as deduced from calculations made with the aid of the treatise by Burch and compared with data contained in the following and other sources:-

American Institute of Electrical Engineers Transactions, Volume 31, Page 1473. "The Relation of Central Station Generation to Railway Electrification"- by Samuel Insull.

American Institute of Electrical Engineers Transactions, Volumn 31, Page 741. "Freight Train Tests on an Electric Interurban Railway"- S.T.Dodd.

Column h gives the kilowatt hours per year, being the product of Column f and Column g, increased by 25% to allow for extra power required by trains in wintertime on account of cold and for heating passenger cars.

Column i gives the assumed load factors for the different kinds of service as deduced from the previously mentioned papers and other sources.

Column j gives the maximum demand at the contacts based on the load factor given in Column i, being equal to the total kilowatts per year divided by (8760) the number of hours in a year, and the load factor.

From this table we arrive at the conclusion that the total kilowatt-hours at the contacts required per year by all the steam railroads of the United States is 59 527 500 000 kilowatt-hours, and the total maximum demand at the contacts is 10 925 795 kilowatts.

It is reasonable to assume that the proportional maximum demand for any given railroad or group of railroads would be in proportion to the number of locomotives in service. The total number of locomotives in service in the United States during the year 1910 was 58 947, therefore the average maximum demand at contacts per locomotive in service was $\frac{10\ 925\ 795}{58\ 947} = 185.4$ kilowatts. And the total

TABLE III.

Total Power Required by Steam and Electric Railways, Jointly Electrified.

a	b	c	d	e	f	g	h	i	j	k
Group	Locomotives in Service	Kilowatt-Hours per Year at Contacts			Maximum Demand at Contacts			Maximum Demand at Power Plant Thousands of Kw.	Normal Rating Power Plant Thousands of Kw.	Load Factor on Power Plant %
		Steam Roads Millions of Kw.Hrs.	Electric Roads Millions of Kw.Hrs.	Total all Roads Billions of Kw.Hrs.	Steam Roads Thousands of Kw.	Electric Roads Thousands of Kw.	Total all Roads Thousands of Kw.			
I	3 297	3 310	518.	3.82	608	146.	754	1 078	862	72.3
II	13 607	13 670	1 865.	15.53	2 512	527.	3 030	4 340	3 475	73.0
III	8 994	9 040	622.	9.66	1 659	176.	1 835	2 620	2 095	75.1
IV	3 102	3 115	113.8	3.22	572	32.3	604	864	691	76.3
V	4 700	4 725	243.8	4.96	868	68.3	939	1 339	1 072	75.6
VI	10 707	10 770	890.0	11.66	1 976	251.	2 227	3 180	2 548	74.5
VII	2 480	2 492	59.4	2.55	458	16.8	474	678	543	76.6
VIII	5 971	6 000	377.0	6.37	1 102	106.5	1 208	1 726	1 381	75.3
IX	2 427	2 435	199.7	2.63	447	56.4	503	720	577	74.4
X	3 662	3 680	637.0	4.31	676	179.7	855	1 224	979	71.9
Total U.S.	58 947	59 237	5 525.7	64.76	10 878	1 560.0	12 438	17 769	14 223	74.2

average kilowatt hours per year per locomotive in service was

$$\frac{59\ 273\ 500\ 000}{58\ 947} = 1\ 004\ 000 \text{ kilowatt hours.}$$

7. All Steam and Electric Railways Jointly Electrified.-- Table III was compiled to determine the total power required by the combined steam and electric railways of the United States.

Column a gives the group numbers.

Column b gives the locomotives in service during 1910 for each group.

Column c gives the total kilowatt-hours required by each group per year, being the product of Column b and 1 004 000, the average kilowatt hours required per year per locomotive in service.

Column d gives the kilowatt-hours required per year by the electric railways, by groups, as developed in Table I, Column j.

Column e gives the total kilowatt-hours required per year by both steam and electric railways, by groups, being the sum of Column c and Column d.

Column f gives the maximum demand at contacts for present steam railroads, by groups, being the product of Column b and 185.4 kilowatts, the maximum demand at contacts per locomotive in service.

Columng gives the maximum demand at contacts, by present electric railways, as obtained from Table I, Column k.

Column h gives the total maximum demand at contacts for the combined steam and electric railways, being the sum of Column f and Column g.

Column i gives the maximum demand at power generating stations assuming 70 per cent efficiency between generators and contacts.

Column j gives the normal rating of the generating equipment necessary based on an overload capacity for two hours of 25 per cent.

Column k gives the load factor on power plants in per cent.

III. POWER PLANTS.

8. Types.-- In determining upon the types of power plants best adapted to the various localities, we have eight principal types to select from, as follows:-

1. Steam turbine-electric stations burning coal.
2. Hydro-electric stations.
3. Producer gas engine-electric stations.
4. Natural gas engine-electric stations.
5. Crude oil engine-electric stations.
6. Gas engine-electric stations burning producer gas with coke by-product.
7. Steam turbine-electric stations burning fuel oil.
8. Steam turbine-electric stations burning natural gas.

Type 1, Steam turbine-electric stations burning coal were found the most adaptable and economical, except in localities where good steam coal is expensive, or where water power is available in large quantities.

Type 2, Hydro-electric stations were used in all localities where sufficient water supply is available, except where steam coal is very cheap and obtainable in large quantities.

Even in some localities where steam turbine plants are used, it might prove, on special investigation, that a hydro-electric plant would furnish cheaper power, but, owing to the impossibility of determining, offhand, without such special investigation the cost of hydro-electric developments, the power cost as for a steam plant was used.

Type 3, Producer gas engine-electric stations were used in a few cases in localities where steam coals are expensive and hard to obtain, and where low grade fuel, such as lignite and peat, are available.

Type 4, Natural gas-engine-electric stations were omitted principally on account of the indefinite nature of the supply of natural gas, and also on account of the high first cost and rather unsatisfactory conditions in the present stage of development of the gas engine from an operating standpoint.

Type 5, Crude oil engine-electric stations. It was necessary to omit these also, owing to the recent advance in the price of crude oil to two and three times its former value, making the cost so high as to be prohibitive in competition with other types of stations.

Type 6, Gas engine-electric stations using producer gas with coke by-product were omitted, owing to the unsatisfactory operation of gas engines, as well as the high first cost of plant.

In an investigation, in which the writer took part recently on a plant of this type, it was found that, figuring the cost of the gas to the gas engine at nothing, the cost of power with a gas engine plant was greater than it could be developed for in a steam turbine plant located at the mines.

Type 7, Steam turbine-electric stations, burning fuel oil. These were also omitted fromconsideration, owing to the high and fluctuating price of oil.

Type 8, Steam turbine-electric stations burning natural gas were omitted from consideration owing to the indefinite nature of the supply of natural gas.

9. Costs.-- On Plate I are given curves showing the cost of power per kilowatt-hour for the different types of plants used. Curves are plotted on a cost of fuel per 1 000 000 British Thermal Unites base, in the case of fuel consuming plants; and on a first cost of plant per kilowatt base for hydraulic plants.
All plants were assumed to be of at least 100 000 kilowatt capacity, and the load factor was taken at 70 per cent.

1. Steam Turbine-Electric Stations Burning Coal -

First cost per kilowatt............ $50.00

Boiler and furnace efficiency ..... 75 per cent.

Steam, per kilowatt hour .... $16\frac{1}{2}$ pounds.

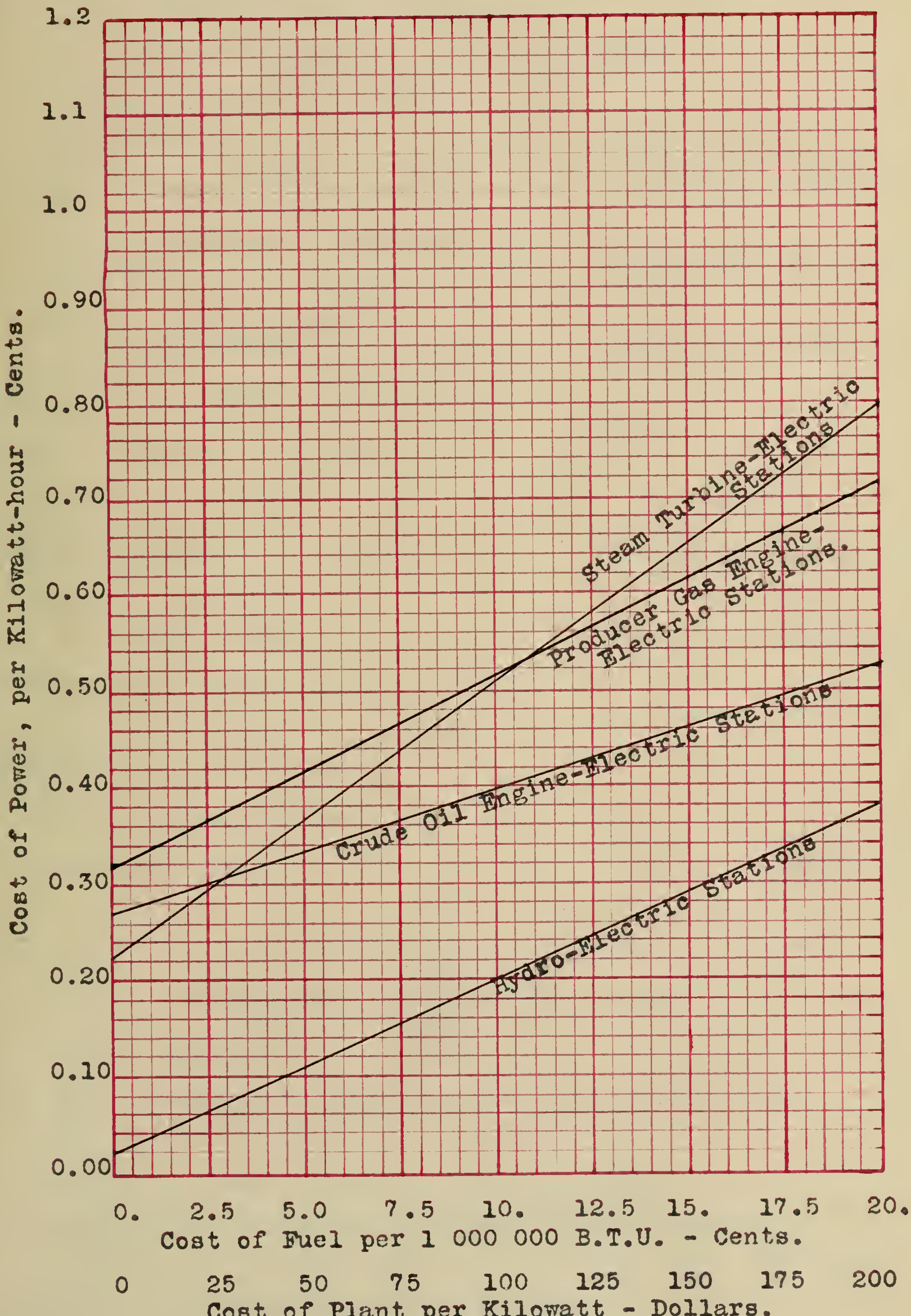
Fixed Charges - 11 per cent = 0.089 ¢ per kilowatt hour

Operating expenses, exclusive of fuel = 0.133 ¢ per kilowatt hour

Total operating charges, exclusive of fuel = 0.222 ¢ per kilowatt hour.

PLATE I.

Cost of Power per Kilowatt-hour.



2. Producer Gas Engine-Electric Station.-

First cost per kilowatt $90.00

British Thermal Units of fuel per kilowatt = 20 000 B.T.U.

Fixed Charges - 12 per cent = 0.175¢ per kilowatt hr.

Operating expenses, exclusive of fuel = 0.140¢ per kilowatt hr.

Total operating charges, exclusive of fuel = 0.315¢ per kilowatt hr.

3. Crude Oil Engine-Electric Plants.-

First cost per kilowatt $90.00

Thermal efficiency of plant .... 27 per cent

Fixed charges - 11 per cent = 0.171¢ per kilowatt hr.

Operating expenses, exclusive of fuel = 0.10 ¢ per kilowatt hr.

Total operating charges, exclusive of fuel = 0.27 ¢ per kilowatt hr.

4. Hydro-Electric Stations.-

Fixed charges - 11 per cent.

Operating expenses 0.02 ¢ per kilowatt hr.

Table IV develops the first cost and operating costs of power generating stations for the different groups.

Column a, Group numbers.

Column b, Total capacity of power plants, as obtained from Table III, Column j.

Column c, Types of plants selected for each group.

Column d, Capacity of plants of different types, given in Column c.

Column e, Cost of fuel per ton of 2 000 pounds.

TABLE IV.

POWER PLANT COSTS.

a Group	b Total Capacity of Power Plants	c Type of Plants	d Capacities of Different Types of Plants K.W.	e Cost of Fuel per 2 000 Pounds	f Heat Content of Fuel per pound B.T.U.	g Cost per 1 000 000 B.T.U. Cents	h Cost of Power per Kw.Hr. Cents	i First Cost of Plant Per Kw. $	j First Cost of different Types of Plants. $
I	862 000	Water	150 000	----	-- ---	- --	0.20	100	15 000 000
		Steam	312 000	2.50	14 000	8.95	0.49	50	15 600 000
		Steam	400 000	2.25	13 000	8.65	0.44	50	20 000 000
II	3 475 000	Water	1 000 000	- --	-- ---	- --	0.192	90	90 000 000
		Steam	2 475 000	1.00	13 000	3 85	0.33	50	123 750 000
III	2 095 000	Water	500 000	- --	-- ---	- --	0.20	100	50 000 000
		Steam	1 595 000	1.00	13 000	3.85	0.33	50	79 750 000
IV	691 000	Water	100 000	- --	-- ---	- --	0.245	125	12 500 000
		Steam	491 000	.85	14 000	3.03	0.31	50	24 550 000
		Steam	100 000	2.00	14 000	7.15	0.425	50	5 000 000
V	1 072 000	Water	200 000	- --	-- ---	- --	0.25	125	25 000 000
		Steam	472 000	1.00	13 000	3.85	0.33	50	23 600 000
		Producer Gas	400 000	1.25	9 000	6.95	0.45	100	40 000 000
VI	2 548 000	Water	500 000	- --	-- ----	- --	0.22	110	55 000 000
		Steam	1 298 000	1.00	12 000	4.17	0.34	50	64 900 000
		Steam	500 000	1.50	13 000	5.77	0.39	50	25 000 000
		Producer Gas	250 000	1.25	7 500	8.85	0.49	100	25 000 000
VII	543 000	Water	100 000	- --	-- ---	- --	0.245	125	12 500 000
		Steam	100 000	1.50	13 000	5.77	0.39	50	5 000 000
		Steam	343 000	1.50	10 500	7.15	0.425	50	17 150 000
VIII	1 381 000	Water	181 000	- --	-- ---	- --	0.245	125	22 625 000
		Steam	500 000	1.35	12 000	5.20	0.37	50	25 000 000
		Steam	700 000	1.00	12 000	4.17	0.305	50	35 000 000
IX	577 000	Producer Gas	400 000	0.90	700	6.43	0.44	100	40 000 000
		Steam	177 000	2.00	10 500	9.53	0.49	50	8 850 000
X	979 000	Steam	100 000	1.75	10 500	8.33	0.46	50	5 000 000
		Water	879 000	- --	-- ---	- --	0.29	150	131 850 000
U.S.	14 223 000						$0.32\frac{1}{3}$	71.00	997 460 000

TABLE IV (Continued)
POWER PLANT COSTS.

Group	k Total First Cost of Plants. $	l Load Factor on Power Plants %	m Power Output per Year Millions Kw.Hrs.	n Operating Charges. Interest %	o Interest Amount Dollars	p Depreciation Taxes and Insurance %	q Depreciation Taxes and Insurance Amount Dollars	r Operating Expenses Per Kw.Hr. Cents	s Operating Expenses Amount = m x r Dollars	t Total Operating Charges o + q + s Dollars
I	50 600 000	72.3	.950	5	750 000	6	900 000	.02	190 000	1 840 000
			1 975	5	781 000	6	936 000	.401	7 925 000	9 642 000
			2 535	5	1 000 000	6	1 200 000	.351	8 900 000	11 100 000
II	213 750 000	73.0	6 390	5	4 500 000	6	5 400 000	.02	1 278 000	11 178 000
			15 800	5	6 190 000	6	7 430 000	.241	38 100 000	51 720 000
III	129 750 000	75.1	3 285	5	2 500 000	6	3 000 000	.02	657 000	6 157 000
			10 480	5	3 990 000	6	4 780 000	.241	25 300 000	34 070 000
IV	42 059 000	76.3	668	5	625 000	6	750 000	.02	133 700	1 508 700
			3 280	5	1 227 000	6	1 472 500	.221	7 250 000	9 949 500
			668	5	250 000	6	300 000	.336	2 245 000	2 795 000
V	88 600 000	75.6	1 324	5	1 250 000	6	1 500 000	.02	264 800	3 014 800
			3 124	5	1 180 000	6	1 415 000	.241	7 530 000	10 125 000
			2 648	5	2 000 000	7	2 800 000	.275	7 280 000	12 080 000
VI	34 650 000	74.5	3 265	5	2 750 000	6	3 300 000	.02	653 000	6 703 000
			8 480	5	3 247 000	6	3 895 000	.251	21 300 000	28 442 000
			1 632	5	1 250 000	7	1 750 000	.315	5 140 000	8 140 000
VII	34 650 000	76.6	670	5	625 000	6	750 000	.02	138 000	1 513 000
			670	5	250 000	6	300 000	.301	2 014 000	2 564 000
			2 300	5	858 000	6	1 028 500	.336	7 730 000	9 616 500
VIII	82 025 000	75.3	1 193	5	1 132 500	6	1 357 500	.02	238 600	2 728 600
			3 295	5	1 250 000	6	1 500 000	.281	9 270 000	12 020 000
			4 620	5	1 750 000	6	2 100 000	.216	9 975 000	15 825 000
IX	48 850 000	74.4	2 607	5	2 000 000	7	2 800 000	.265	6 900 000	11 700 000
			1 153	5	425 000	6	531 500	.401	4 620 000	5 576 500
X	136 850 000	71.9	629	5	250 000	6	300 000	.371	2 330 000	2 880 000
			5 530	5	6 592 500	6	7 911 000	.02	1 107 000	15 610 500
U.S.	997 460 000	74.2	92 436	5	49 873 000		60 907 000		188 294 100	299 074 100

Column f, Heat content of fuel per pound.

Column g, Cost of fuel per 1 000 000 British Thermal Units.

Column h, Cost of power per kilowatt hour, as obtained from Plate I.

Column i, Assumed first cost of power plant per kilowatt.

Column j, First cost of power plants.

Column k, Total first cost of power plants for each group.

Column l, Load factor of power plants for each group as obtained from Table III, Column k.

Column m, Total kilowatt hours developed per year.

Column n, Interest charge in per cent.

Column o, Interest charge in dollars.

Column p, Charge for depreciation, taxes and insurance, per cent.

Column q, Charge for depreciation, taxes and insurance, dollars.

Column r, Operating expenses per kilowatt hour.

Column s, Operating expenses, dollars.

Column t, Total operating charges, dollars.

IV. TRANSMISSION LINES.-

10. Length.- Transmission line voltage was taken at 150 000 volts. Assuming the most economical distance of power transmission to be 200 miles based on 750 volts per mile of transmission, the theoretical, or average distance apart of power stations, would be

$$2 \times \sqrt{200^2} \div 2 = 288 \text{ miles, or say, } 300 \text{ miles.}$$

Then, in order to have all power plants connected with adjacent ones by trunk lines, would require (2 x 300) = 600 miles of transmission trunk lines for each 90 000 (300 x 300) square miles of territory covered; or for all of the United States -

$\frac{2\ 000\ 947\ 159}{90\ 000}$ x 600 = 3 275 miles of trunk transmission lines.

Allowing 25 miles for transmission from sub-stations, would make it necessary to have branch transmission lines from the trunk lines every 50 miles, running in one direction only,- i.e. North and South, and the total miles of branch transmission lines for the whole of the United States would be as follows:-

Average breadth of the United States, North and South = 1 200 miles

Average length of the United States, East and West = 2 250 miles

Number of branch lines running North and South	= 2 250 ÷ 50 =	49
Less number of trunk lines	= 2 450 ÷ 300 =	8
Net number of branch lines		41

Total length of branch lines (1 200 - 50) x 41 = 47 200

11. Cost.--Taking the cost of construction of the trunk transmission lines at $25 000.00 per mile, and of the branch transmission lines at $8 000.00 per mile, as is substantiated by data available, the total cost of transmission lines is as follows:-

3 275 miles trunk transmission lines @ $25 000.per mile	=$81 900 000.
47 200 miles branch transmission lines @ $8 000.per mile	=378 000 000.
Total cost of all transmission lines to serve the railways of the United States	$459 900 000.

12. Operating Charges.- The operating charges are assumed as follows:-

Interest at 5 per cent	$ 22 995 000.
Depreciation, taxes and insurance at 4 per cent	18 396 000.
Maintenance at 2 per cent	9 198 000.
Energy losses at 10 per cent of $299 074 100. (Table 4, Column t) =	29 907 410.
Total operating charges	$ 80 496 410.

V. SUB-STATIONS.-

13. General.-- It is assumed that all present steam lines would be operated by means of transformer sub-stations, and that all present electric lines would be operated by means of motor generator sub-stations.

The total capacity of sub-stations and power losses are determined as follows:-

Steam Railroads:-

Kilowatt-hours per year,
Table III, Col.c, ... = 59 237 000 000

Power Factor 62%

Overload capacity 25%

Transmission losses from sub-stations 10%

Total capacity transformer

$$\text{Sub-stations} = \frac{59\ 237\ 000\ 000}{8760 \times .62 \times 1.25 \times .90} = 9\ 700\ 000 \text{ kilowatts.}$$

Yearly output of transformer

$$\text{Sub-stations} = \frac{59\ 237\ 000\ 000}{.90} = 65\ 820\ 000\ 000 \text{ kilowatt-hrs.}$$

Taking transformer efficiency at 97%, the yearly energy losses of transformer

$$\text{substations} = 65\ 820\ 000\ 000 \times \frac{3}{97} = 2\ 034\ 000\ 000 \text{ kilowatt-hours.}$$

Electric Railways:-

Kilowatt-hours per year, Table III,
Column d .... = 5 525 700 000

Power factor .... = 30%

Overload capacity .... = 25%

Transmission losses from sub-stations = 10%

Total capacity of motor-generator

$$\text{Sub-stations} = \frac{5\ 525\ 700\ 000}{8760 \times .30 \times 1.25 \times .90} = 1\ 873\ 000 \text{ kilowatts.}$$

Yearly output of motor-generator

$$\text{Sub-stations} = \frac{5\ 525\ 700\ 000}{.90} = 6\ 140\ 000\ 000 \text{ Kilowatt-hours.}$$

Taking motor-generator substation efficiency at 91%, the yearly energy losses of motor-generator sub-stations =

$$6\ 140\ 000\ 000 \times \frac{9}{91} = 607\ 000\ 000 \text{ kilowatt-hours.}$$

14. Transformer Sub-station Costs.-- The first cost of transformer stations was taken at $12.00 per kilowatt, therefore

First cost = 9 700 000 kilowatts @ $12.00 per kilowatt = $116 400 000

The operating costs were assumed as follows:-

Interest at 5%	5 820 000
Depreciation, taxes and insurance at 5%,	5 820 000
Operating expenses, exclusive of power losses, 65 820 000 000 kilowatt-hours at 0.10¢ per kilowatt-hour	65 820 000
Energy losses 2 034 000 000 kilowatt-hours @ (0.32-1/3 + 10%) 0.356¢ per kilowatt-hour	7 250 000
Total operating charges	$84 710 000

15. Motor-generator sub-station Costs.- The first cost of motor-generator sub-stations was taken at $30.00 per kilowatt, therefore we have -

First cost of motor-generator sub-stations 1 873 000 kilowatts, @ $30.00 per kilowatt	$56 190 000
Interest @ 5% ....,.	2 809 500
Depreciation, taxes and insurance @ 5%	2 809 500

TABLE V.

SUB-STATION COSTS

For all Railways in the United States, Electrified.

Type Sub-station	First Cost	Operating Charges				
		Interest	Depreciation Taxes and Insurance	Operating Expenses	Energy Losses	Total
Transformer	$116 400 000	$5 820 000	$5 820 000	$65 820 000	$7 250 000	$ 84 710 000
Motor-generator	56 190 000	2 809 500	2 809 500	9 210 000	2 160 000	16 989 000
Total	$172 590 000	$8 629 500	$8 629 500	$75 030 000	$9 410 000	$101 699 000

Operating expenses, exclusive of power
losses, 6 140 000 000 kilowatt-hours,
@ 0.15¢ per kilowatt-hour $9 210 000

Energy losses (607 000 000 kilowatt-
hours) @ 0.356¢ per kilowatt-hour 2 160 000

Total operating charges $16 989 000

16.- Total Sub-station Costs.-- Table V gives the summarized cost data on Sub-stations.

VI. Electrification of Tracks and Equipment of Present Steam Railroads.-

17.- Cost of Electrification of Tracks.-- The costs of electrification of tracks as contained in Table VI are the most accurate figures obtainable from the data available:-

TABLE VI.

Electrification Cost of all present Steam Railroads in the United States.

Number of Tracks	Number of Miles	Cost to Electrify Per Mile	Total Cost of Electrification
4	1 488.78	$25 000.	$ 37 230 800.
3	717.61	15 000.	10 755 050.
2	19 452.35	10 000.	194 523 000.
1	219 172.01	4 000.	876 800 000.
Yard and Sidings	85 581.93	2 000.	171 450 000.
Total			1 290 758 850.

18.- Costs of Electric Locomotives.-- In the report of the Interstate Commerce Commission we find that the heating surface of all the steam locomotives in service during 1910 was 125 195 129 square feet. Taking the figure as given by W.F.M.Goss of 0.43 H.P.

per square foot of heating surface, would make the horse power of all the locomotives in service 0.43 x 125 195 129 = 53 800 000 horse power.

From the data available, it is fair to assume that electric locomotives could be purchased in quantities for $20.00 per horse power, which would make the cost of electric locomotives 53 800 000 x $20.00 = $1 076 000 000.

19.- Operating Expenses of Electrified Steam Railroads.-- The principal factors in the operating expenses of steam railroads, which are affected by electric operation, are -

1. Maintenance of permanent way.
2. Repairs and renewals of locomotives.
3. Engine and roundhouse wages.
4. Fuel and power for trains.
5. Miscellaneous items.
6. Repairs and renewals of overhead work.

The accompanying Table VII, Column a, gives the operating charges for all steam railroads of the United States, as taken from the Interstate Commerce Commission Reports, and divided in accordance with the above named items. Taking the items up in order we have the following statement by J.Shaw before the British Institute of Civil Engineers, Nov.1909.- "Mercy railway records for three years of steam traction show that the effect of electric traction on the maintenance of the permanent way has been to reduce the cost of maintenance per ton-mile from 0.0416 cents to 0.0240 cents." This is equivalent to a saving of 42.3%.

This figure for the railroads of the United States for 1910

was 0.032 cents per ton-mile which, if reduced to 0.024 cents per ton mile is equivalent to a saving of 25%, which figure has been used.

As to the second item, Repairs and renewals of locomotives,- Stillwell states that the maintenance and up-keep of electric locomotives may be placed at 2½% per annum, while the rate for steam locomotives is 20% per annum, which, when considering the cheaper cost of steam locomotives, is equivalent to a saving of 80%.

Pomerey states the reduction in maintenance cost of electric locomotives below steam locomotives is 60%.

Burch makes the reduction 47.8%.

Taking the average of this data makes the saving in repairs and renewals of locomotives 62.6%.

Burch summarized the saving effected by electric traction due to reduction in engine and roundhouse wages at 36%.

The same authority places the saving on all other items, except fuel and power for trains, at 2½% and makes an addition of 1% of the total for repairs and renewals of overhead work.

The proper allowances, in accordance with this data, have been made in Table VII.

20.- Fixed Charges for Electric Locomotives.--Taking the interest charge for electric locomotives at 5%, we have -

Interest charge for electric locomotives
= $1 076 000 000 @ 5% .... = $53 800 000

Depreciation of electric locomotives is already taken care of under heading VI-19 "Operating Expenses of Electrified Steam Railroads".

Taking taxes and insurance at 2%, we have taxes and insurance charge for electric locomotives = 1 076 000 000 @ 2% .... = 21 520 000

TABLE VII.

Operating Costs of Electrified Steam Railroads in the United States.

Item	Steam Operation United States 1910	Electric Operation		Operation Cost by Electric Traction.
		% Saving	Amount Saving	
Maintenance of Way and Structures	$368 394 260	25	$92 300 000	$276 094 260
Repairs and re-newals of locomotives	156 253 231	62.6	92 900 000	63 353 231
Engine and Roundhouse Wages	178 192 968	36.	64 100 000	114 092 968
Fuel and power for trains	231 573 851	100	231 573 851	-----------
Miscellaneous items	887 836 513	2½	22 200 000	865 636 513
Repairs and renewals of overhead work	---------	-1	-18 222 508	18 222 508
Total -	$1 822 250 823	26.6	$484 851 343	$1 337 399 480

21.- Fixed Charges for Electrification of Roadway.-- Taking the interest charge at 5%, we have -

Interest charge for electrification of roadway = 1 290 758 850 @ 5% .... = $64 537 942

Taking depreciation, taxes and insurance at 4%, we have -

Depreciation, taxes and insurance for electrification of road = 1 290 758 850 @ 4% .... = $51 630 354

VII. Deductions and Allowances.-

22.- General.-- In making allowances for capital investment in present electric power generating stations, present steam locomotives, and such other items as would be displaced by joint electrification, a deduction was made for their probable present value. In reality, however, should a project of this sort be attempted, the equipment thus displaced would be worn out in service, and result in a decrease of the depreciation charges as a whole, but the result would be the same.

23.- Allowances for Present Electric Railway Power Plants.-- Assuming that the total normal rating of power plants which serve present electric railways is the same as that calculated for motor generator sub-stations under heading V-13, and taking the present average value of these power plants at $55.00 per kilowatt, we have -

Capital allowance for present electric railway power plants 1 873 000 kilowatts @ $55.00 per kilowatt..	=	$103 000 000
Interest allowance for present electric railway power plants @ 5%	=	5 150 000
Depreciation, taxes and insurance, allowance for present electric railway power plants @ 6%	=	6 180 000
Taking the operating cost of present electric railway power plants at 3¢ per car-mile, the allowance is $0.03 x 2 124 660 000	=	63 739 800
Total allowance for operating charges of present electric railway power plants	=	$ 75 069 800

24.- Allowances for Present Steam Locomotives.-- The total horse power of all present steam locomotives has already been assumed to be 53 800 000, heading VI-18. Taking the average value per horse power at $12.00, we have -

Capital allowance for present steam locomotives 53 800 000 horse power @ $12.00 per horse power	$645 600 000
Interest allowance for present steam locomotives @ 5%	32 280 000
Taxes and insurance allowance for present steam locomotives @ 2½%	16 140 000
Allowance for depreciation and operation has been made under heading VI-19, "Operating Expenses of Electrified Steam Railroads".	
Total allowance for operating charges except depreciation and operating expenses	$ 48 420 000

25.- Allowances for Present Electrified Portion of Steam Railroads.--Burch in his treatise on "Electric Traction for Railway Trains" gives estimated costs of steam railroads in the United States which have been electrified, by the close of 1910, as $69 500 000.

Assuming that this expenditure is divided as follows, we have the following costs on the portion of the steam railroads in the United States which were electrified at the close of 1910.-

Power Plants	30%	=	$20 850 000
Sub-stations	5%	=	3 475 000
Lines	45%	=	31 275 000
Motor equipment	20%	=	13 900 000
Total			$69 500 000

We have then -

a - Deductions due to Power Plants of Present Electrified Portion of Steam Railroads -

Capital	$20 850 000
Fixed Charges, interest @ 5%	1 042 500
Depreciation, taxes and insurance @ 6%	1 051 000
Total fixed charges	$ 2 093 500

Operating Expense is included under heading VI-19.

b - Deductions due to Sub-stations -

Capital	$3 475 000
Fixed charges, interest @ 5%	173 750
Depreciation, taxes and insurance @ 5%	173 750
Total Fixed Charges	$ 347 500

Operating expense is included under heading VI-19.

c - Deductions due to Electrification of Lines -

Capital	$31 275 000
Fixed charges, interest @ 5%	1 563 750
Depreciation, taxes and insurance @ 4%	1 251 000
Total fixed charges	$ 2 814 750

Operating expense is included under heading VI-19.

d - Deductions due to Motor Equipment -

Capital	$13 900 000
Fixed charges, interest @ 5%	695 000
Depreciation is included under heading VI-19	
Taxes and insurance @ 2%	278 000
Total fixed charges, except depreciation	$ 973 000

Operating expense is included under heading VI-19.

VIII. Summary and Conclusions.-

26.- Summary.- Table VIII is a summary of all the first costs, fixed charges and operating expenses, entering into the joint electrification of all the steam and electric railroads of the United States as of June 30, 1910. The table gives the total costs for joint electrification, the deductions therefrom for considerations treated under heading VII, and the net amounts, separately, for all of the items entering into the subject, as well as a grand total of all these items, which is as follows:-

Total additional capital required for joint electrification of all railways in the United States		$ 3 178 608 855
Interest - 5%	$158 930 442	
Depreciation, taxes and insurance	136 009 104	
Total Fixed Charges on additional investment		294 939 546
Total Operating Expenses		1 585 499 190
Total charges against electrification		$ 1 880 438 736

27. Conclusions.- The total operating expenses for all steam railroads in the United States for year ending June 30,1910 were, see table VII .... $ 1 822 250 823

The total operating expenses for all electric railways in the United States during 1910 were, see Table I,Column h,	323 780 000
Total operating expenses for all steam and electric railways in the United States in 1910	$ 2 146 030 823
Total charges against joint electrification of all railways in the United States, Table VIII	1 880 438 736
Saving by joint electrification	$ 265 592 087

TABLE VIII.

Summary of All Joint Electrification Costs.

a	b	c	d	e	f
Item	Capital	Interest	Depreciation Taxes and Insurance	Operating Expenses	Total Electrification Charges
Power Plants -					
Total	$ 997 460 000	$ 49 873 000	$ 60 907 000	$ 188 294 100	$ 299 074 100
Deductions	103 000 000	5 150 000	6 180 000	63 739 800	75 069 800
Deductions	20 850 000	1 042 500	1 051 000	(See Roadway)	2 093 500
Net	873 610 000	43 680 500	53 676 000	124 554 300	221 910 800
Transmission Lines-					
Total	459 900 000	22 995 000	18 396 000	39 105 410	80 496 410
Deductions	(See Roadway)				
Sub-stations-					
Total	172 590 000	8 629 500	8 629 500	84 440 000	101 699 000
Deductions	3 475 000	173 750	173 750	(See Roadway)	347 500
Net	169 115 000	8 455 750	8 455 750	84 440 000	101 351 500
Locomotives-					
Total	1 076 000 000	53 800 000	21 520 000.*)		75 320 000 x
Deductions	645 600 000	32 280 000	16 140 000 *)	(See	48 420 000 x
Deductions	13 900 000	695 000	278 000 *)	Roadway)	973 000 x
Net	416 500 000	20 825 000	5 102 000 *)		25 927 000 x
Roadway -					
Total	1 290 758 850	64 537 942	51 630 354)	1 337 399 480	1 453 567 776
Deductions	31 275 000	1 563 750	1 251 000)		2 814 750
Net	1 259 483 850	62 974 192	50 379 354	1 337 399 480	1 450 753 026
All Items -					
Total	3 996 708 850	199 835 442	161 082 854	1 649 238 990	2 010 157 286
Deductions	818 100 000	40 905 000	25 073 750	63 739 800	129 718 550
Net Amounts for Electrification	$3 178 608 855	$158 930 442	$136 009 104	$1 585 499 190	$1 880 438 736

* Taxes and insurance only.

x Except depreciation and operation.

Interest charge included in electrification charges	\$ 158 930 442
	424 522 529

In other words joint electrification would pay

$\frac{424\ 522\ 529}{3\ 178\ 608\ 850}$ = 13-1/3% on the investment.

This is highly gratifying for the joint electrification of all railways when considered in connection with the many other advantages and the likely increase in revenue which would result, and apparently the subject is worthy of a more detailed investigation.